Available online at www.ejournals.uofk.edu

UofKEJ Vol. 7 Issue 2 pp. 21- 24 (August 2017)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Single Axis Passive Solar Tracker Performance Evaluation

Ali Omer Ahmed, Ahmed I. Goubti, Abdallah Y. Abdallah, Mohamed A. Ahmed

National Energy Research Center, Ministry of Higher Education and Scientific Research
Khartoum, Sudan, (E-mail:aliomer017@yahoo.com)

Abstract: A passive solar tracker was designed and constructed in GIAD Industrial Complex. The tracker was tested in Soba region, in the premises of the National Energy Research Center. The test consisted of two parts; the first was testing the tracking error by placing a pyranometer on the tracker and comparing the beam radiation readings with that of the maximum theoretical beam radiation possible if the tracker was tracking without errors. The second test was comparing the power output of 8, 50Wp photovoltaic modules attached onto the tracker in tracking mode to the same modules on the tracker fixed in a straight position. The array is inclined to 15.5^o facing South. The results showed that most of the tracking error was within the range of 7.37 %. The photovoltaic array comparison test showed that the tracker is most effective in the morning hours from 9:00 to 11:00 and in the afternoon from 15:00 to 17:00. The increase of power output of the tracked array to the fixed array was 12.67% on the day of 9thDecember and 14.39% on the day of 11thApril.

Keywords: *Solar energy; Passive solar tracker; Photovoltaic modules; Pyranometer*

1. INTRODUCTION

A passive solar tracker was constructed in GIAD Industrial Complex. The system was a single axis tracker (East to West motion) and can be manually tilted at the declination angle of the sun. The tracker consisted of low boiling point fluid-filled containers (refrigerant 134a) with shadow plates integrated into the sides of the array mounting structure. The containers were connected together with flexible piping. As long as the array is facing directly at the sun, the shades cover each container equally.

When the array is no longer facing directly at the sun, one container is exposed to more heat from the sun. This causes the fluid to boil out of that container into the other one. Now the shaded container has more fluid in it and is heavier. The array will drop down in the direction of the shaded container until the shading equalizes on the two containers again.The declination of the tracker can be manually adjusted and that could be done monthly.

The tracker could take up to eight 50 Wp solar photovoltaic modules, each of dimension 0.47m x 0.96m. The tracker was tested on the premises of the National Energy Research Center, Soba, Khartoum.The test consisted of two parts; the first was testing the tracking error by placing a pyranometer on the tracker and comparing the beam radiation readings with that of the maximum theoretical beam radiation possible if the tracker was tracking without errors. The second test was comparing the power output of 8, 50Wp photovoltaic modules, 4 modules in series and 2 panels in parallel attached onto the tracker in tracking mode and to the same array in straight position. In both tests the inclination of the system was kept at 15.5^o facing south.

2. MATERIALS AND METHODS

2.1 Tracking Error Test

A pyranometer was attached on to the tracker; a second pyranometer was placed nearby in a horizontal position. Hourly readings were taken from both pyranometers from 9:00 to 17:00 local standard time. The readings were respectively the global radiation and diffuse radiation. To acquire the beam radiation, the diffuse radiation was measured by shading the glass globe of the pyranometer. This would prevent the beam radiation reaching the instrument sensor; the diffuse radiation was subtracted from the global radiation.

Calculations were done on the horizontal pyranemeter readings to obtain the maximum hourly beam radiation the tracker could attain if tracking is without error. The results were then compared with the actual readings of the pyranometer on the tracker. The mathematical model for the maximum beam radiation that can be obtained without tracking errors is shown below.

Zenith angle θ_z: The Zenith angle is angle between the solar beam radiation and the vertical to the horizontal plane [1]. θ_z can be calculated from Equation 1:

$$\cos\theta_z = \cos\emptyset\cos\delta\cos\omega + \sin\emptyset\sin\delta \quad (1)$$

Where ϕ is the latitude which is the angular location north or south of the equator. For Khartoum ϕ = 15.5^o and δ is the solar declination that is the angular position of the sun at solar noon with respect to the plane of the equator. δ varies between +23.45^o to –23.45^o over the course of the year. The variation is due to the inclination of the earth's axis and its orbit around the sun.

The solar declination can be calculated from Equation (2) [1]:

$$\delta = 23.45\left(\sin\frac{360\,(284+n)}{365}\right) \quad (2)$$

$$1 \le n \le 365$$

where,

n is the number of day in the year.

ω (hour angle) is an angular measure of time and is equivalent to 15° per hour, it can be calculated from Equation 3 [1]:

$$\omega = (solar\ time - 12) * 15 \quad (3)$$

Solar Time is the time used in all sun angle relations. It does not coincide with the local standard time which can be converted to solar time by applying two corrections. The first is a constant correction for the difference in longitude between the observers meridian (Longitude) and the meridian on which the standard local time is based. The sun takes 4 minutes to transverse 1^o of the longitude. The second correction is the equation of time, which takes into account the earth's rate of rotation which affects the time taken by the sun to cross the observer's meridian[1]. The difference in minutes between solar time and standard time is:

$$Solar\ time = (standard\ tme - 1) \pm 4(L_{st} - L_{loc}) + E \quad (4)$$

where,

Lst is the standard meridian for the local time zone.

Lloc is the longitude of location in question.

E is the equation of time in minutes and can be determined by Equation 5:

$$E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B \quad (5)$$

$$B = 360 * \frac{(n-81)}{364}$$

Inserting φ and the values calculated in Equations (2) and (3) in (1) to get Cos θz [1]

The tracker is set at an inclination equal to the Latitute of the location, facing south. The tracker rotates continuously from east to West following the sun from sun rise to sunset. The value of the tracking angle of the beam radiation can be calculated from Equation 6 [2]

$$\cos\theta = \cos\delta \quad (6)$$

where θ is the angle of incidence between the beam radiation on a surface and the normal of that surface.

The geometric factor R_b the ratio of beam radiation on a tilted surface to that of radiation on a horizontal surface at any time can be calculated by the Equation 7 [1]

$$R_b = \frac{\cos\theta}{\cos\delta} \quad (7)$$

The expected beam radiation is calculated from real values on a horizontal surface.

$$G_{bT}Tracking\ (calculated) = G_b * R_b \quad (8)$$

where G_b is the irradiance on a surface in W/m^{2}andG_{bT} is the irradiance on a tracking surface.
The results are then compared with measured values of beam radiation from the pyranometer attached to the tracker.

2.2 Photovoltaic Power Output Comparison Test

Eight and fifty Wp photovoltaic module were attached to the tracker with an inclination of 15.5^o facing south. The 8 modules were arranged in two panels each having 4 modules.

The global solar radiation readings were taken hourly with the corresponding current and voltage output from the array using a 60 ohm rheostat variable resister. The resistance was varied from open circuit up to short circuit at each hour [3]. The hourly readings were taken when the tracker is in tracking mode and compared with the readings when the tracker is manually set in a straight line. In all cases the inclination was at 15.5^o. I-V curves were drawn using excel computer programs. From the I-V curves, maximum current (I_{max}) and maximum voltages (V_{max}) were determined. A photographic view of the solar tracker is shown in **Fig. 1**.

Module output power as calculated by Equation (9) [4]:

$$P = Imax\ x\ Vmax \quad (9)$$

Fig. 1. Solar Tracker with Photovoltaic Modules

The output powers of the array in tracking mode, and when placed in straight lines were compared and the hourly percentage improvement calculated. The daily improvement was calculated by integrating the area under the tracking photovoltaic power output using Trapezoid Method and the area under the fixed photovoltaic power output in Figures4 and 5 and calculating the daily percentage increase.

3. RESLUTS AND DISCUSSION

The results of the Tracking Error Test are presented graphically in **Figs. 2** and **3**.The results of the Photovoltaic Power Output Test are depicted in **Figs. 4** and **5**.

Using Trapezoid Method, the area under of the fixed panel power output curve and the area under the tracking panel power output in **Figs 4** and **5** were calculated and the percentage increase in power output from the tracking panel output was found. The area numerically integrated, under the fixed array photovoltaic power output curve in **Fig. 4** was 1936.78 units. The area, numerically integrated, under the tracking array photovoltaic power output curve in **Fig. 4** was 2182.25 units. The daily percentage power output increase was 12.67 %.

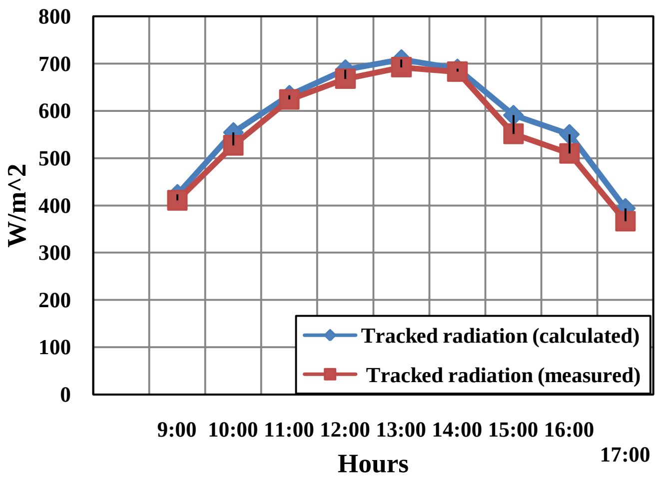

Fig. 2. Solar Beam Radiation Vs Time of Day, Dec. 9, 2015

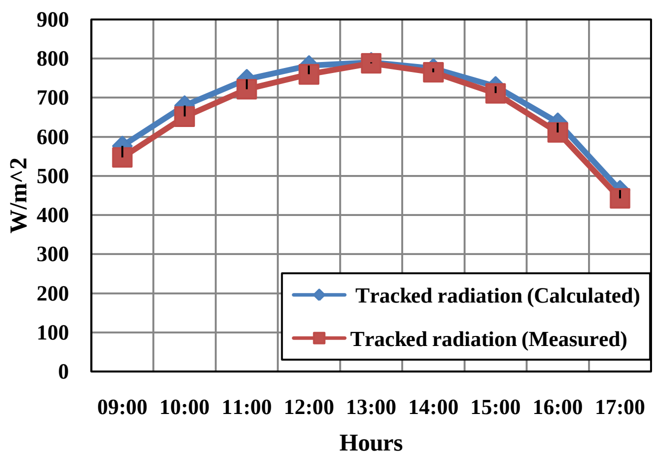

Fig. 3. Solar Beam Radiation Vs Time of Day, April 11, 2016

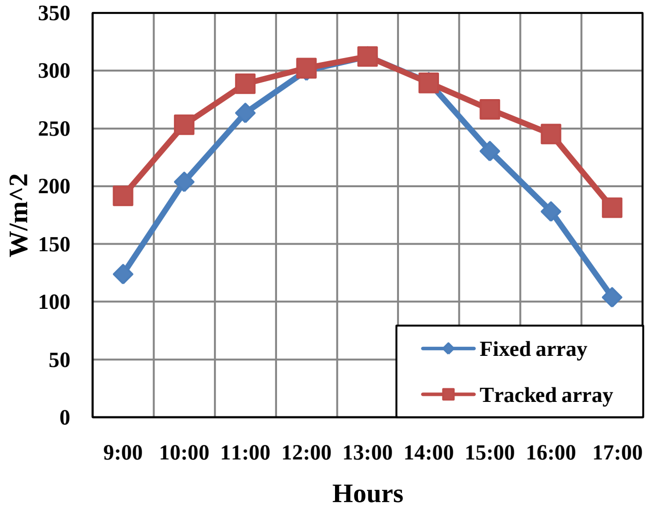

Fig. 4. Tracked Photovoltaic power output Vs Fixed Photovoltaic power output, Dec. 9, 2015

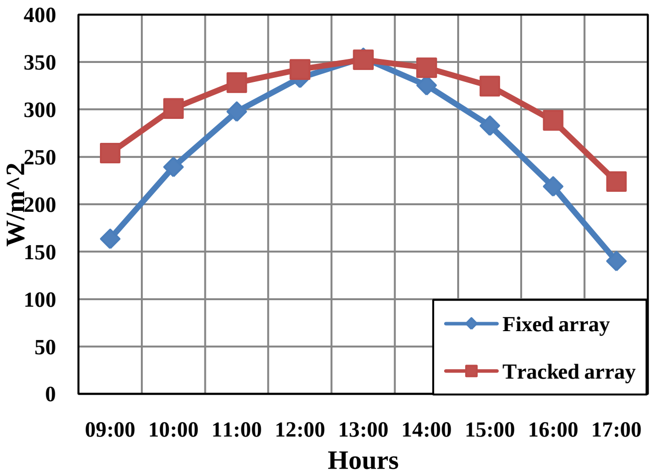

Fig. 5. Tracked Photovoltaic power output Vs Fixed Photovoltaic power output, April 11, 2016.

The area numerically integrated under the fixed array photovoltaic power output curve in **Fig. 5** was 2204.67. The area numerically integrated under the tracking array photovoltaic power output curve in **Fig. 5** was 2521.91. The daily percentage power output increase was 14.39 %.

In **Figs 2** and 3 the results show that most of the tracking errors are within the range of 7.37%. The daily percentage power output increase on the 9th of December was 12.67 %. The daily percentage power output increase on the 11th of April was 14.39 %.

In conclusion the tracker's accuracy was satisfactory and the experiments showed that an improvement in performance of solar systems can be achieved with passive solar trackers.

4. CONCLUSIONS

In conclusion the tracker's accuracy was satisfactory and the experiments showed that an improvement in performance of photovoltaic solar systems can be achieved with passive solar trackers. The solar tracker is most effective in the morning and afternoon hours.

It was recommended that the tracker is to be optimally designed to save material and minimize cost. A computer model is to be programmed using the mathematical model shown in section 2 to predict the tracker performance throughout the year. Furthermore, an economic evaluation is recommended to assess whether a tracking system is more cost effective to that of increasing the number of modules to a fixed frame.

REFERENCES:

[1] John A. Duffie, William A. Beckman, Solar Energy of Thermal Processes, Second Edition, Wiley Interscience, USA, June 1991.
McGraw-Hill, New Delhi, 1997

[2] H.P. Grag, J. Prakash, Solar Energy Fundamental and Application, Second Edition, Tata

[3] Photovoltaic System Design, Laboratory Manual, Florida Solar Energy Center, Cape Canaveral, Florida 1988.

[4] G. D. Rai, Solar Energy Utilization, Fifth Edition, Khanna Publishers, Delhi, 2011.